Mixed Metal Oxides as primary dust condensates OR the "corundum conundrum"

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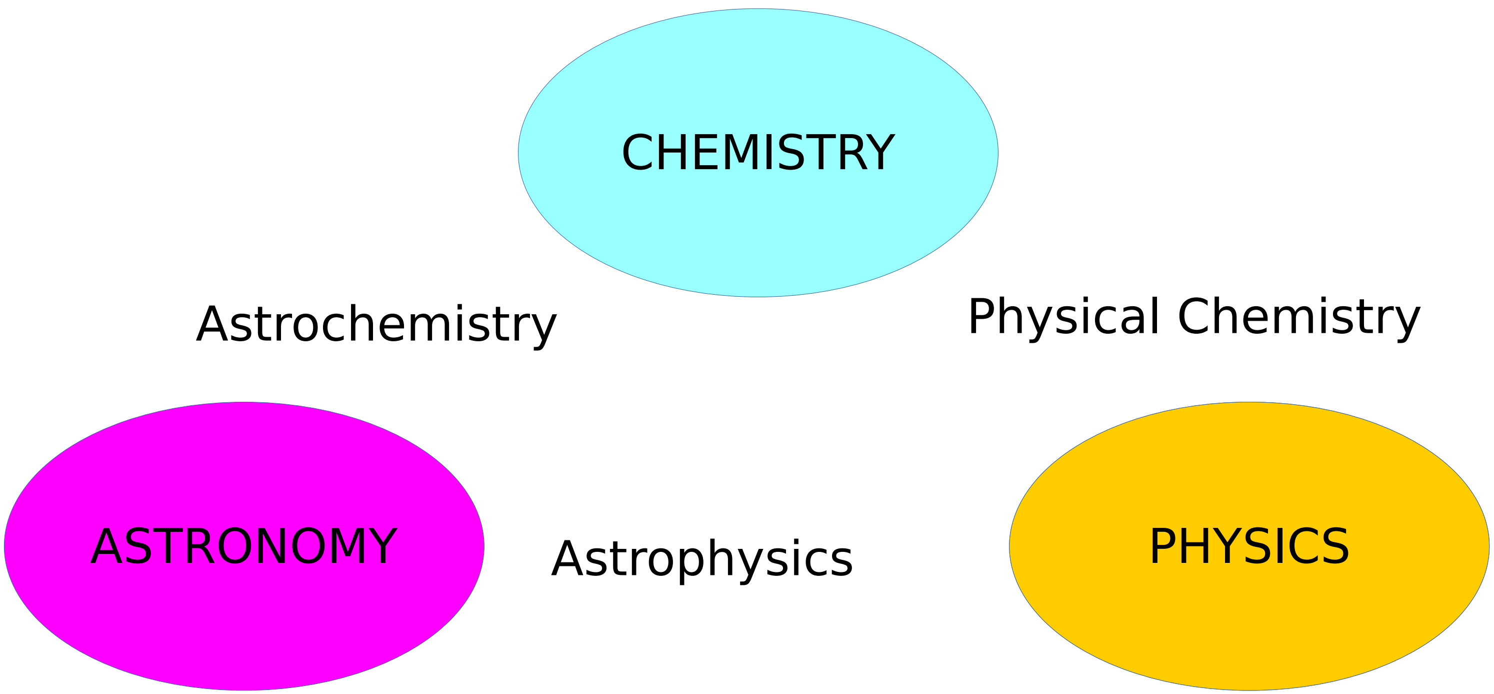
Dust formation:
An interdisciplinary study



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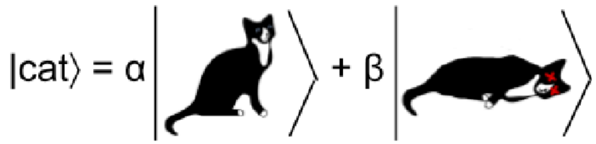


THEORY

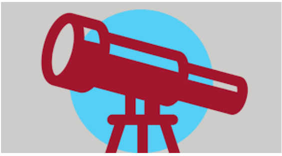
Molecular
abundances
Dust features
Gas conditions

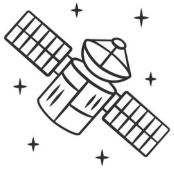
Dust composition:
Meteoritic stardust
Analogues of dust
Reaction rates

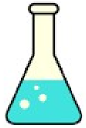
OBSERVATIONS

LABORATORY
EXPERIMENTS

Spectroscopic
constants
Level transitions

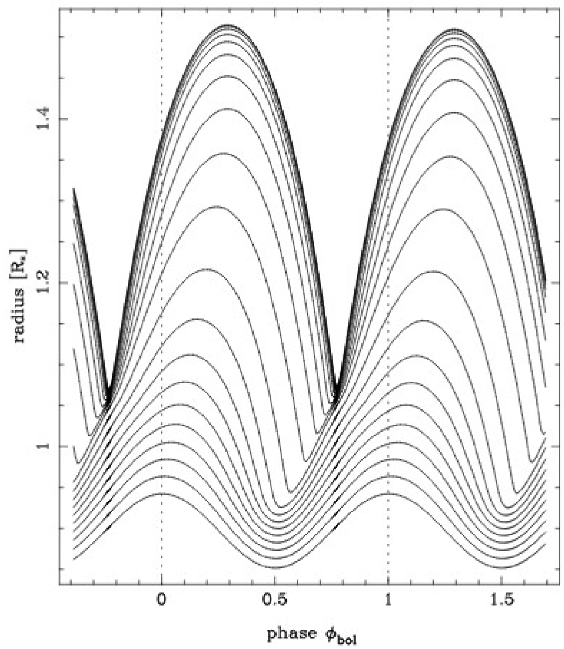




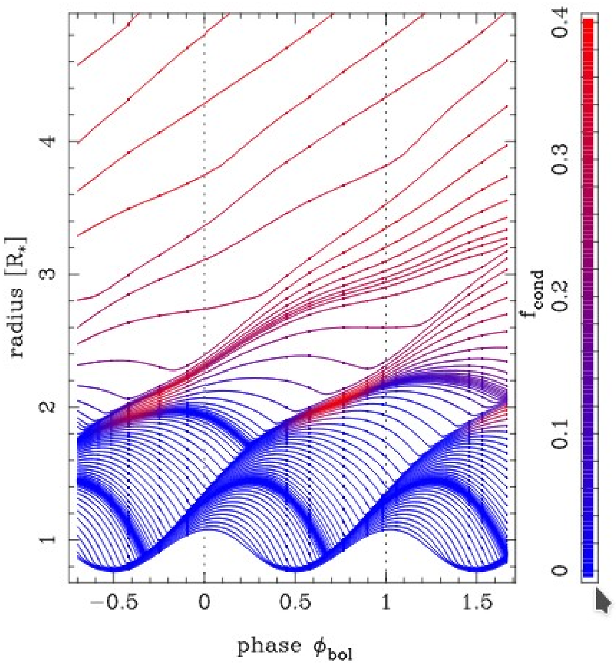


AGB stars loose mass

- **Stellar mass-loss is a result of stellar pulsations & dust formation**



Without condensates
Hoefner and coworkers

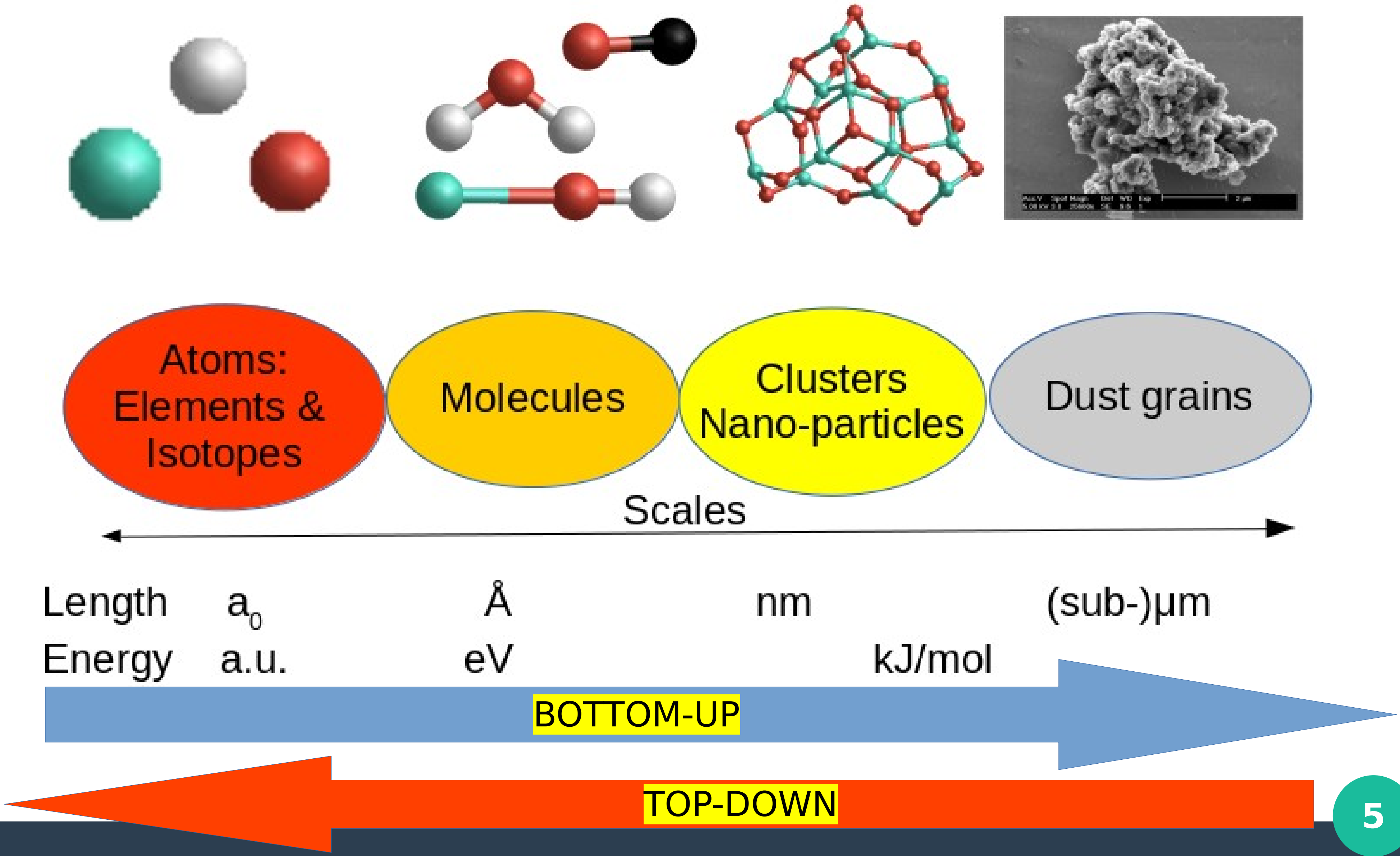


pre-existing dust seeds

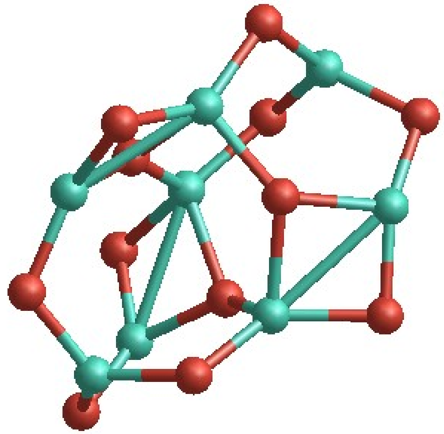
“Pulsations alone cannot drive a mass loss” Woitke (2006)

VULCAN project
Cristallo et al. 2021

Nucleation theory: Nano clusters



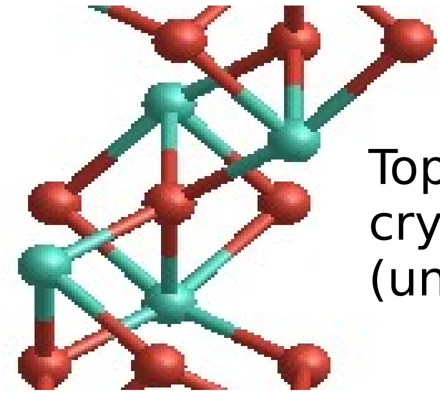
Bottom-up nucleation



Bottom-up

Most stable $(Al_2O_3)_4$

5 Å (0.5 nm)

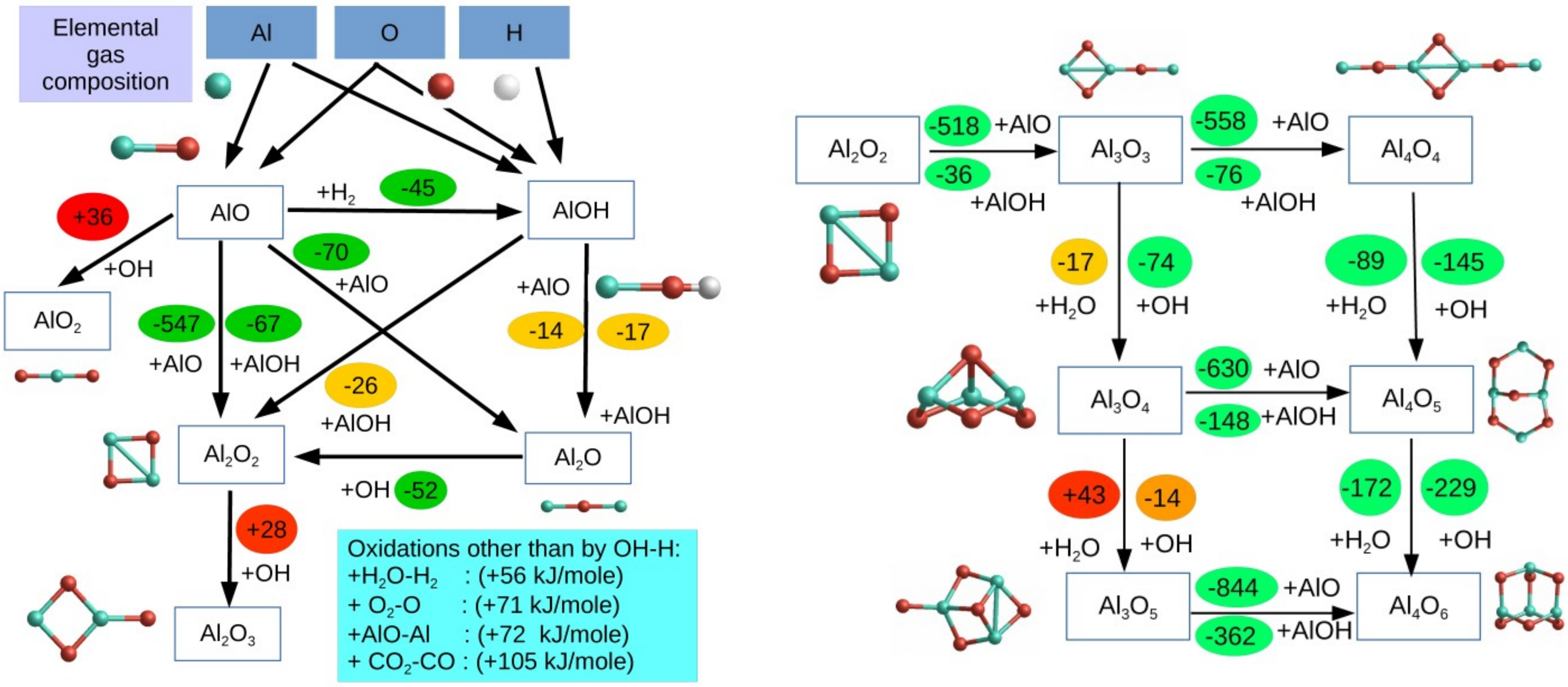


Top-down crystal cut (unstable)

Clusters: Quantum and finite size effects, different bond characteristics
=> potential energies, structures, charges, bonds differ significantly from the crystal (bulk material)
=> Top-down derived clusters **do not represent favourable structures on the (sub-)nano scale**

Chemical networks: Viability

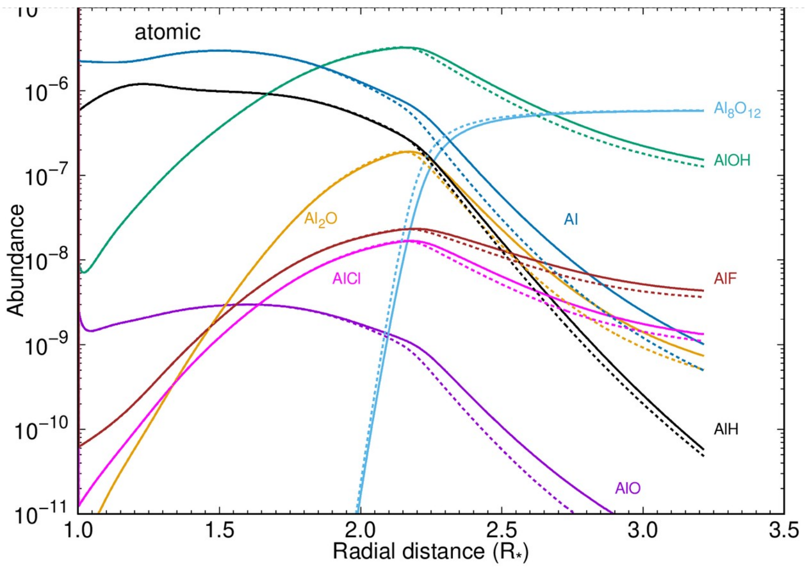
Gobrecht et al 2022

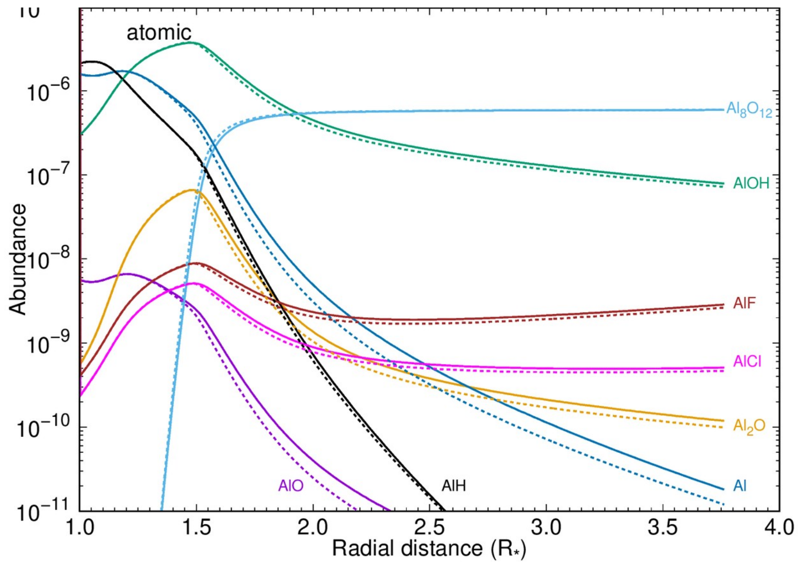


The monomer formation is unfavorable (from atomic gas, AlO and AlOH), but the dimer formation is energetically viable

Results: Non-pulsating models

Monotonic Outflow describe with β-velocity law



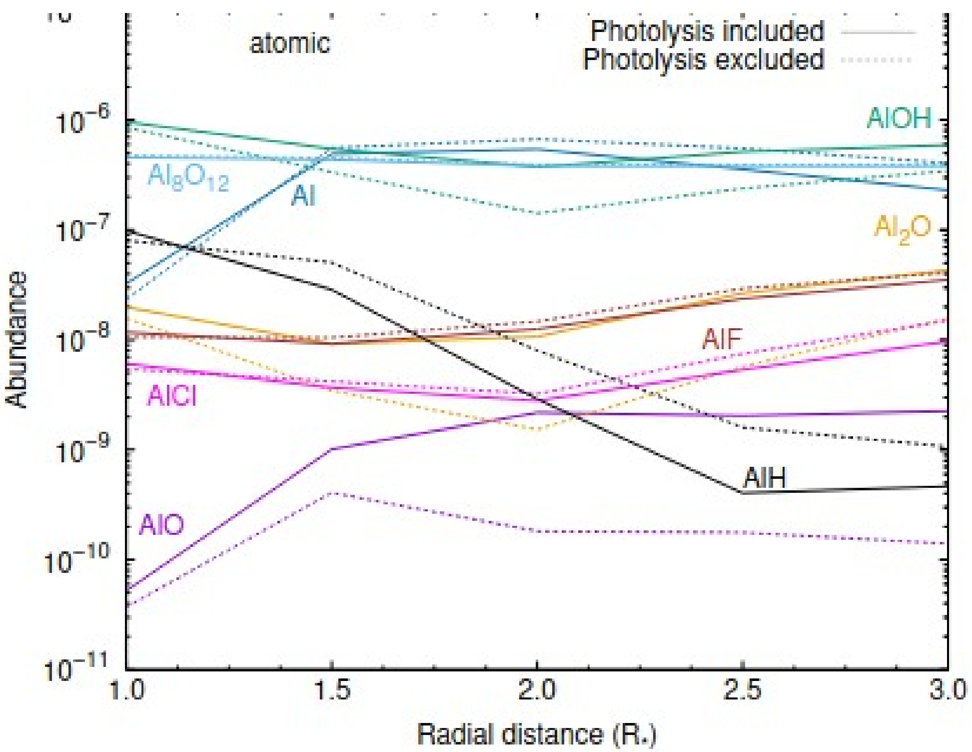


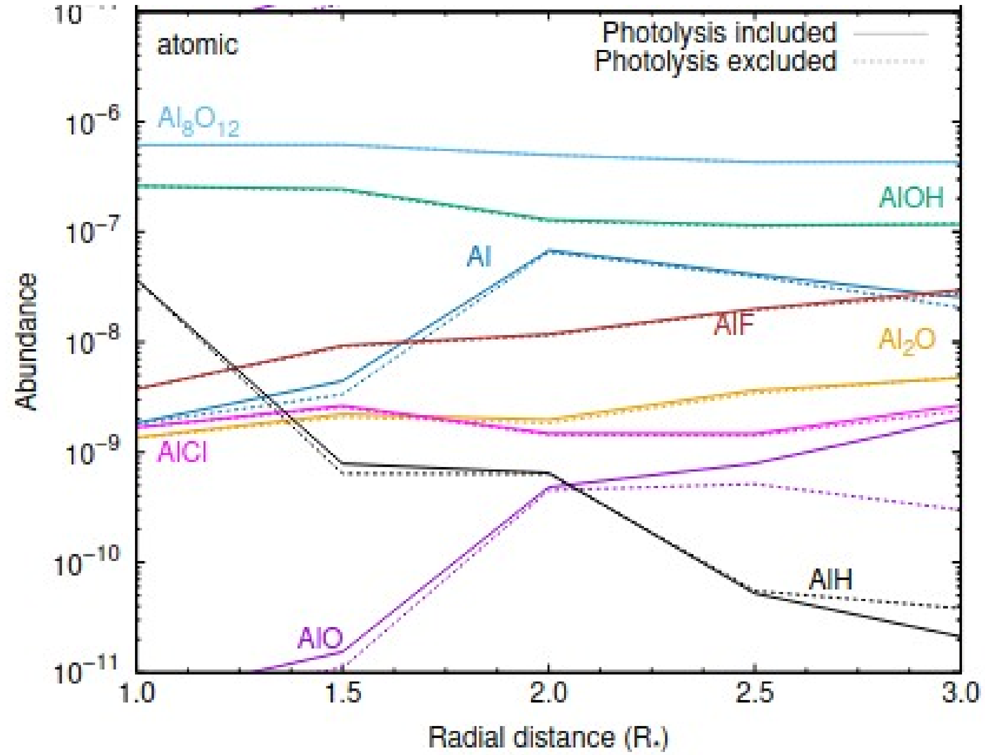
Semi-Regular AGB star (SRV-like)
n_0=1.e14 cm^{-3}, T_0=2400K,
v_∞=5.7 km/s

Regular AGB star (Mira-like)
n_0=4.e14 cm^{-3}, T_0=2000K,
v_∞=17.7 km/s

Gobrecht et al 2022

Results: Pulsating models II





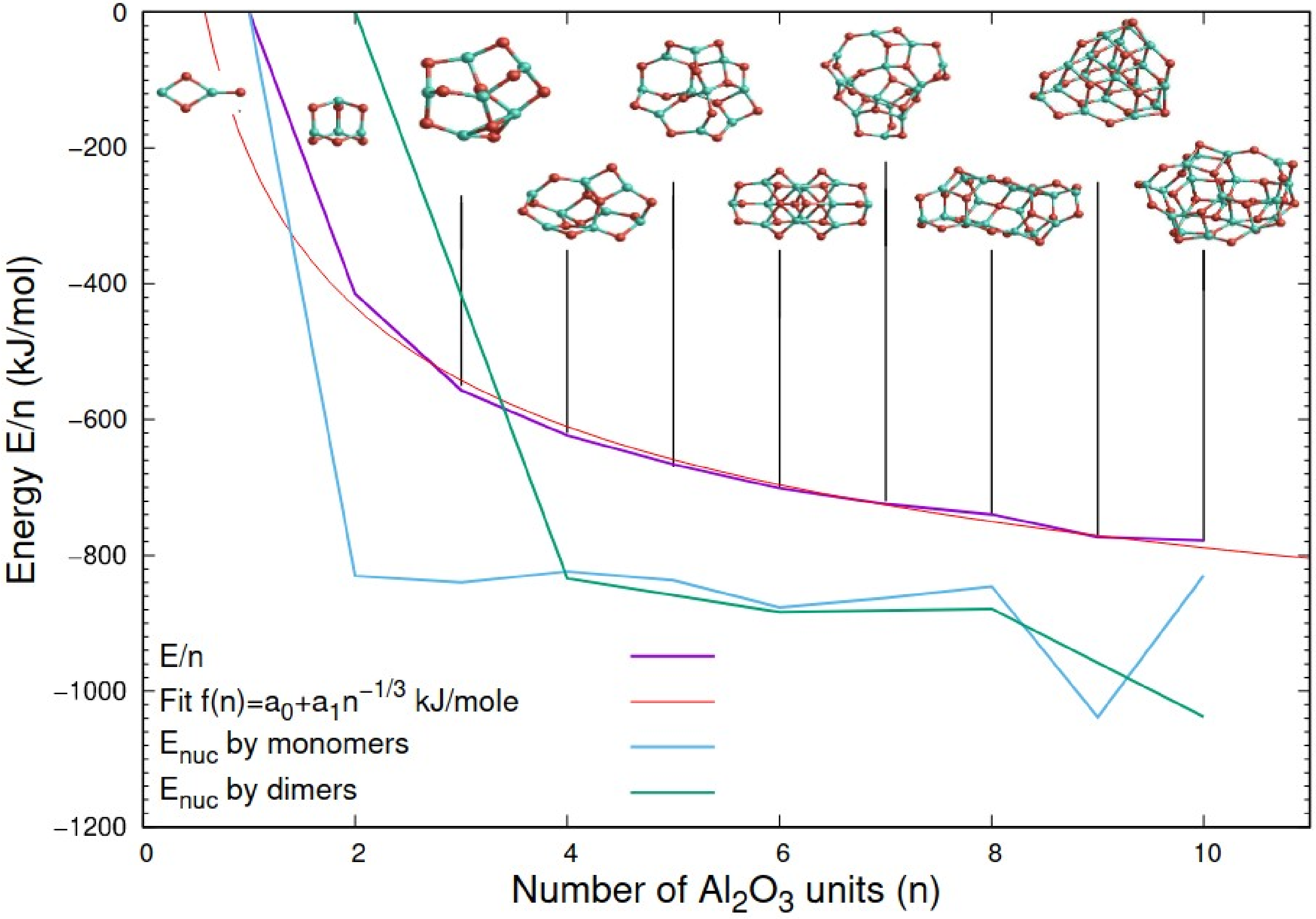
SRV-type AGB star
(P=332d, vs=10 km/s

MIRA-type AGB star
P=450d, vs=20 km/s

Molecule and cluster abundances as a function of **radial distance** after a complete pulsation cycle

Gobrecht et al 2022

Results: Homogeneous Nucleation



New global minima candidates for n=7-10

Some size more favourable (n=3,9), than others (n=1,8)

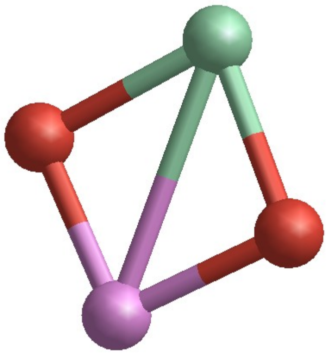
Energy of larger clusters can be approximately extrapolated by a bottom-up fit

Homogeneous nucleation is energetically downhill

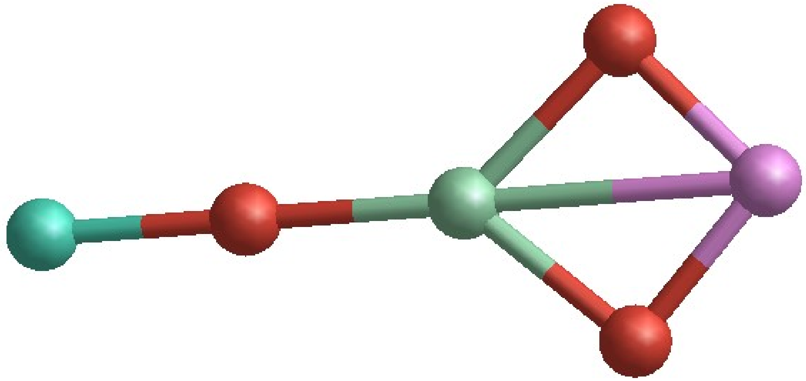
Gobrecht et al 2022

Mixed metal oxide clusters

- Ternary oxides (i. e. with more than 1 metal) can be even more favourable



SiTiO2



AlTiSiO4

Summary

- Bottom-up nucleation and chemical-kinetics are key to model dust formation realistically
- Homogeneous alumina nucleation is viable proceeding via the dimer (n=2) without involving the monomer (n=1)
- Heterogeneous nucleation is a likely alternative in a chemical rich AGB star atmosphere

Thanks for your attention!

Questions?